Monitoring California's Hardwood Rangelands Using Remotely Sensed Data

Presented at the Fifth Oak Symposium on Oaks Woodlands

October 24, 2001

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Abstract

As human and natural forces continue to alter the hardwood landscape, resource agencies, county planners and local interest groups find it increasingly important to monitor and assess these alterations. The California Land Cover Mapping and Monitoring Program (LCMMP), a cooperative program between the U.S. Forest Service and the California Department of Forestry and Fire Protection, is addressing statewide long-term monitoring strategies using Landsat Thematic Mapper (TM) satellite imagery. The LCMMP creates seamless vegetation and monitoring data across California's landscape for regional assessment across all ownerships and vegetation types.

This paper focuses on the hardwood rangeland region from Shasta County in the north to Kern County in the south, extending from 300 to 5000 feet in elevation. Results indicate that most of the hardwoods did not undergo change between 1991 and 1996. However, large change did occur in concentrated areas from wildfire, harvest and development. Regeneration of hardwoods was also detected.

The LCMMP directly addresses CDF's need for a long-term monitoring strategy to inform discussion of issues centered on California's hardwood rangelands. CDF now has the ability to identify trends in hardwood rangeland structure, health, resource use and other factors that affect long-term viability across large regions. The LCMMP provides critical information on the impacts management decisions and natural forces have on the environment. This information includes the actual location and extent of change, three levels of vegetation cover increase and decrease and the cause of change. Knowing the location and extent of vegetation change provides a picture of the distribution and concentration of change areas. Levels of change give an indication of vegetation removal, vigor or health. Understanding what is causing these changes creates an awareness of the impacts change agents have on the landscape. This information is useful to assess the effectiveness of existing policies, programs, management activities and regulations, and to develop alternatives as needed (e.g., county voluntary guidelines for oak woodland management).

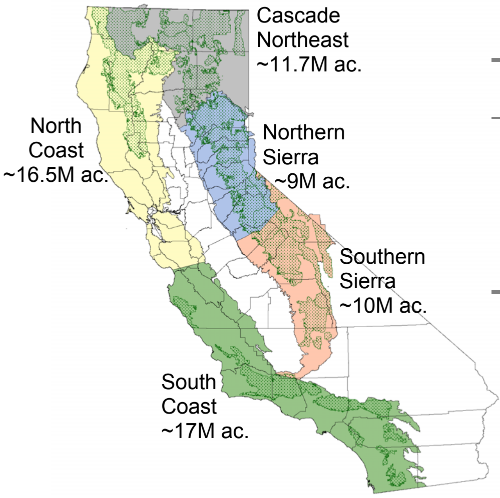
Hardwood rangelands are one of California's most expansive and biologically diverse ecosystems (Pavlik et al. 1991). They cover just over 10 million acres and occur in 47 of 58 counties, with most in private ownership (Greenwood et al. 1993). Characterized by an oak overstory and a grass, forb and brush understory, hardwood rangelands provide many ecological and commercial values, including wildlife habitat, water quality, erosion control, livestock grazing, vineyard production, recreation and urban centers.

Historically, California's hardwood rangelands have been under constant pressure from intensive agriculture, range production and fuelwood harvesting. Between 1945 and 1988, approximately 1.2 million acres of hardwood rangeland were lost due to agricultural conversion (Bolsinger 1988). More recently, threats are occurring from residential and commercial development and agricultural expansion. Many new developments are emerging in hardwood rangelands because they are predominantly in private ownership and near population centers (Scott et al. 1995). Urban expansion has a profound effect on hardwood resources as development generally fragments the landscape. Agricultural conversion to high value crops, such as vineyards, is increasing particularly in coastal counties (Merenlender 2000). Studies also suggest that many oak species are not naturally regenerating adequately, further impacting this resource (Adams et al. 1990, McCreary 1991).

As human and natural forces (e.g., mortality, wildfire) continue to alter the hardwood landscape, resource agencies, county planners and local interest groups find it increasingly important to monitor and assess these alterations. In 1987, the State Board of Forestry recognized this need and directed the CA Department of Forestry and Fire Protection (CDF), the CA Department of Fish and Game (CDFG), and University of California Cooperative Extension to develop the Integrated Hardwood Range Management Program (IHRMP), a non-regulatory program to resolve hardwood issues through research, education and monitoring (UC and CDF 1994). A long-term effort to address monitoring needs began with the development of a baseline map of California's oak woodlands derived from 1981 aerial photography (Pillsbury et al. 1991). Later, satellite imagery was used to create a more current map of hardwood rangelands and compare it to the earlier aerial photo base map (Pacific Meridian Resources 1994). Satellite data proved to be a useful tool to address monitoring over large areas, when coupled with adequate field verification (UC and CDF 1994).

In 1995, a cooperative program between the US Forest Service (USFS) and CDF was launched to address long-term monitoring strategies (Levien et al. 1996). This program is formally called the California Land Cover Mapping and Monitoring Program (LCMMP). The objective of the LCMMP is to create seamless vegetation and monitoring data across California's landscape for regional assessment across all ownerships and vegetation types. The program uses Landsat Thematic Mapper (TM) satellite imagery to derive land cover change over five-year time periods (Figure 1). These monitoring data provide critical information on the impacts of vegetation change over large areas. They also provide timely data for the CDF and IHRMP to assess statewide trends in hardwood rangeland ecosystems, and for planners, resource managers, landowners, industry, watershed groups and others for land use planning, biological diversity assessment, resource management and sustainable economic development.

Figure 1. Location and extent of project areas with first statewide monitoring schedule.



Project Area	Monitoring Dates (nominal)	Change Data Complete
Southern Sierra	1990 to 1995	1996
Cascade Northeast	1991 to 1996	1997
Northern Sierra	1991 to 1996	1997
South Coast	1993 to 1997	1999
North Coast	1994 to 1998	2000

Method

This paper focuses on the hardwood rangeland region from Shasta County in the north to Kern County in the south, extending from 300 to 5000 feet in elevation. A total of eight TM scene pairs cover the project area (Figure 2). Scene path/row and dates are displayed in Table 1. All images were co-registered using a third-order affine transformation model. The LCMMP detects changes in land cover between two different TM image dates. Images are selected during the late summer season of each year (e.g., August 1991 and 1996) to ensure that the processes of canopy maturation and senescence and the growth cycle of understory grasses do not interfere with actual land cover changes. Steps required to produce a final change image include database building, change processing, change labeling and accuracy assessment.

Figure 2. Location of project area and TM scenes

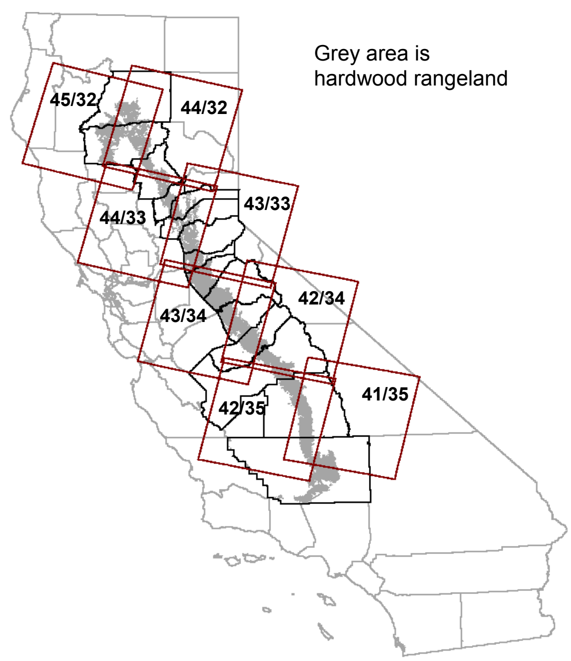


Table 1. TM Imagery for Project Area

Path/Row	Dates	
45/32	6/27/90	8/14/96
44/32	8/26/91	8/07/96
44/33	6/20/90	8/07/96
43/33	7/02/91	7/31/96
43/34	8/16/90	9/15/95
42/34	8/25/90	9/08/95
42/35	8/25/90	9/08/95
41/35	9/0390	9/17/95

Database Building

In this procedure, TM imagery is prepared for processing and a seamless vegetation layer is assembled. The first step in preparing the TM imagery is to register the early date TM image to the later date TM image that is in the same path and row. Registration begins by identifying common features throughout both images on-screen (e.g., road intersections). Approximately 50 to 100 features are located throughout each scene pair. These features are used in a nearest neighbor resampling technique to assign the early date pixel values to the later date pixel locations. Nearest neighbor resampling avoids altering pixel values, therefore maintaining spectral reflectance of ground features. These new pixel locations must be within a one-half pixel of the later date pixels to eliminate any false changes. The images are then radiometrically corrected to account for differences in atmospheric conditions (e.g., haze and water vapor). This correction is accomplished by extracting invariant light (rock outcrops) and dark (water bodies) features from both dates of imagery and running a regression-based correction on the resulting pixels (Schott et al. 1988). The regression equation is applied to the early date TM image to derive normalized pixel values.

Land cover data are used to determine which vegetation types are experiencing change. The LCMMP produces vegetation data using the Classification and Assessment with Landsat of Visible Ecological Groupings (CALVEG) (USDA Forest Service Regional Ecology Group 1981) and Wildlife Habitat Relationships (WHR) (Mayer and Laudenslayer 1988) classification systems. However, geographic extent is not complete for the state; thus, other vegetation data sources are required to attain full project area coverage. Other data sources include a hardwood data layer (CDF layer updated in 1990) and a GAP data layer (created in 1990). Vegetation layers are mosaicked with precedence given to the LCMMP layers, then the updated hardwood layer and finally the GAP layer. GAP data is usually a small component of the seamless vegetation layer and mainly is used to cover the low elevation valley areas.

Change Processing

Co-registered and radiometrically corrected TM imagery is analyzed for change using image processing techniques. A Kauth-Thomas transformation is applied to a 12-band image (bands 1-5 and 7 from each date) (Kauth and Thomas 1976). The following equation is used:

$$B_{t1} = B1(TM_{b1}) + B2(TM_{b2}) + B3(TM_{b3}) + B4(TM_{b4}) + B5(TM_{b5}) + B7(TM_{b7})$$
$$G_{t1} = G1(TM_{b1}) + G2(TM_{b2}) + G3(TM_{b3}) + G4(TM_{b4}) + G5(TM_{b5}) + G7(TM_{b7})$$
$$W_{t1} = W1(TM_{b1}) + W2(TM_{b2}) + W3(TM_{b3}) + W4(TM_{b4}) + W5(TM_{b5}) + W7(TM_{b7})$$

B_{t1} = brightness value for time 1; G_{t1} = greeness value for time 1; W_{t1} = wetness value for time 1.
Bx = brightness coefficient for TM band x; Gx = greeness coefficient for TM band x;
Wx = wetness coefficient for TM band x; TM_{bx} = TM band x reflectance value.

This transformation applies coefficients to each TM band producing a new image depicting changes in brightness, greenness and wetness components (Table 2) (Crist and Cicone 1984). Brightness is a measure of overall reflectance, greenness is related to the amount of green vegetation present in the scene, and wetness correlates to canopy and soil moisture (Crist et al. 1986). The change in BGW differentiates change in vegetation cover over the time period. In order to reduce the amount of information from the resulting BGW change image, we aggregate pixels into polygons using a segmentation algorithm. This algorithm is a multipass algorithm that uses several parameters to define the threshold of similarity between neighboring pixels (Ryherd and Woodcock 1990).

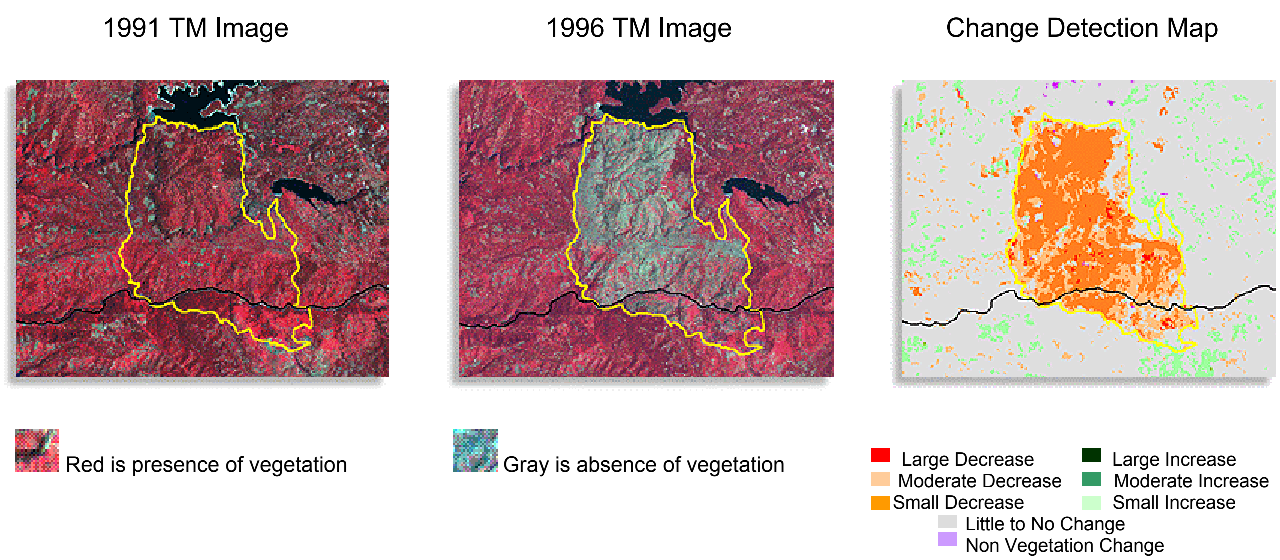
Table 2. Kauth-Thomas Coefficients for TM Imagery

	TM1	TM2	TM3	TM4	TM5	TM7
Brightness	0.2147	0.1975	0.3354	0.3949	0.3593	0.1317
Greenness	-0.2017	-0.1724	-0.3848	0.5116	0.0589	-0.1275
Wetness	0.1067	0.1395	0.2318	0.2408	-0.5029	-0.3233

Change Labeling

The resulting change image is then stratified by individual lifeform type (e.g., conifer, hardwood, shrub) using the composite vegetation layer. An unsupervised classification is applied to each change image by lifeform, which results in approximately 50 change classes per lifeform type change image. Within each of these, categories of similar levels of brightness, greenness and wetness values are assigned to one of nine change classes (Figure 3). Image appearance, photo interpretation, vegetation and topographic maps and bispectral plots (e.g., greenness vs. wetness) aid in assigning the change classes. Each individual lifeform change image is then mosaicked into one project area change map.

Figure 3. Landsat TM imagery and change map with change classes



Decrease and increase change classes represent relative changes in vegetation cover. For example, a small decrease will have less vegetation cover loss than a moderate or large decrease (e.g., a forest thinning compared to a clearcut). The little or no change class indicates that change did not occur or that change was so slight that it could not be detected. The non-vegetation change class accounts for variations in lake or reservoir water levels and snow pack in the higher elevations. A cloud and shadow class is added to account for clouds in the imagery and shadows in the mountainous areas that obscure ground cover making it impossible to determine whether the vegetation had changed or remained stable in these areas.

Accuracy Assessment

A total of 300 randomly selected change areas were compared with known reference information of the same areas. All change classes were represented with sites based on the acreage amount of change (e.g., the little to no change class has the largest acreage, thus contains the most sites). Sites were chosen by randomly selecting change polygons. These areas were interpreted for change using color aerial photography at a scale of 1:15,840, TM imagery and field data. Because the decreasing and increasing change classes are relative to each other (large decrease has more relative change than moderate decrease), the interpretation of the photo or image was subjective, based on the amount of interpreted change.

Cause Verification

An attempt is made to verify cause on all change areas to understand the impacts and relationships the landscape is experiencing. GIS overlay, fieldwork and photo interpretation are used to determine the causes of change areas. The CDF forest practices database, the USFS stand record system database, and the CDF fire history database are overlaid onto the change map to attribute changes caused by harvests, regeneration and wildfires. USFS resource managers interpret change maps by applying local knowledge and fieldwork to identify sources of change on national forest lands. Similarly, IHRMP personnel consult private landowners to identify sources of change in hardwood rangelands. Areas without a causal agent identified through the above processes become the focus of further field efforts and aerial photo interpretation. Despite all these efforts, full coverage of cause verification is not always possible due to the large number of change areas, insufficient information and inaccessible lands.

Results

Total hardwood rangeland area for the project area is approximately 4.7 million acres, with the majority (3.3 million acres) in private ownership. Blue oak woodland, blue oak / foothill pine and montane hardwood WHR types comprise roughly 96 percent of the area. Approximately 463,000 acres underwent some form of change, with 110,000 acres exhibiting a loss in cover and 353,000 acres showing an increase in cover. Table 3 lists acres of hardwood change by WHR types and ownership. Montane hardwood exhibits the largest acreage of decrease (56,305 acres) and blue oak woodland exhibits the largest increase (170,125 acres). Relative to its area, Blue oak woodland and blue oak / foothill pine have the largest percent of change at 11 percent (2 percent decrease and 9 percent increase).

Figures 4 and 5 display the distribution of detected hardwood cover change by county. The positive acreage numbers represent detected hardwood cover increase and the negative numbers represent detected hardwood cover decrease. Within the southernmost counties, the majority of detected blue oak woodland decrease is in Kern and Mariposa counties, while Fresno and Calaveras have the largest amount

Table 3. Acres of Change by Hardwood Cover Type and Owner Class

	National Forest		Other Public		Private		All Owners	
	Acres	%	Acres	%	Acres	%	Acres	%
Blue Oak Woodland								
Large Decrease	17	0	10	0	266	0	293	0
Moderate Decrease	1,151	0	107	0	2,396	0	3,655	0
Small Decrease	4,263	2	969	1	31,771	2	37,003	2
Little or No Change	174,806	66	124,057	87	1,292,333	88	1,591,196	85
Small Increase	41,368	16	8,337	6	87,703	6	137,407	7
Moderate Increase	22,114	8	1,343	1	5,716	0	29,172	2
Large Increase	2,097	1	135	0	1,314	0	3,546	0
Non-Veg. Change	1,728	1	1,418	1	6,642	0	9,788	1
Cloud or Shadow	15,473	6	5,646	4	34,810	2	55,929	3
TOTAL	263,018	100	142,021	100	1,462,951	100	1,867,989	100
Blue Oak / Foothill Pine								
Large Decrease	52	0	162	0	247	0	461	0
Moderate Decrease	267	1	1,027	1	2,057	0	3,352	0
Small Decrease	346	1	2,441	2	8,428	1	11,216	2
Little or No Change	22,242	62	84,010	74	490,591	87	596,843	84
Small Increase	3,064	9	6,867	6	44,626	8	54,558	8
Moderate Increase	1,337	4	1,808	2	2,885	1	6,030	1
Large Increase	76	0	121	0	203	0	400	0
Non-Veg. Change	148	0	9,315	8	2,735	0	12,197	2
Cloud or Shadow	8,095	23	8,255	7	11,696	2	28,046	4
TOTAL	35,628	100	114,006	100	563,469	100	713,103	100
Montane Hardwoods								
Large Decrease	719	0	213	0	3,161	0	4,093	0
Moderate Decrease	5,121	1	860	0	10,695	1	16,676	1
Small Decrease	12,212	2	2,113	1	21,211	2	35,536	2
Little or No Change	550,776	81	161,987	82	1,145,813	89	1,858,576	86
Small Increase	39,800	6	6,875	3	62,288	5	108,963	5
Moderate Increase	13,880	2	2,777	1	7,091	1	23,747	1
Large Increase	1,260	0	975	0	992	0	3,227	0
Non-Veg. Change	1,424	0	914	0	3,435	0	5,773	0
Cloud or Shadow	54,463	8	20,811	11	26,052	2	101,326	5
TOTAL	679,654	100	197,526	100	1,280,739	100	2,157,919	100
TOTAL	978,300		453,553		3,307,159		4,739,011	

of cover decrease in montane hardwood. Fresno and Mariposa counties show a large amount of detected increase within blue oak woodland, while Madera shows large increases in blue oak / foothill pine. Increase in montane hardwood is largest in Fresno County.

Most of the change occurring in the northernmost counties is in detected decreasing classes. Tehama County has the largest amount of cover increase within blue oak woodland and Butte, Nevada and Tehama counties show marked increases in montane hardwood. Hardwood cover decrease within blue oak woodland and blue oak / foothill pine is greatest in Shasta County, while montane hardwood cover decrease is greatest in El Dorado County. The montane hardwood type shows a large amount of cover decrease in all northernmost counties.

Figure 4. Acres of classified change by hardwood type and county

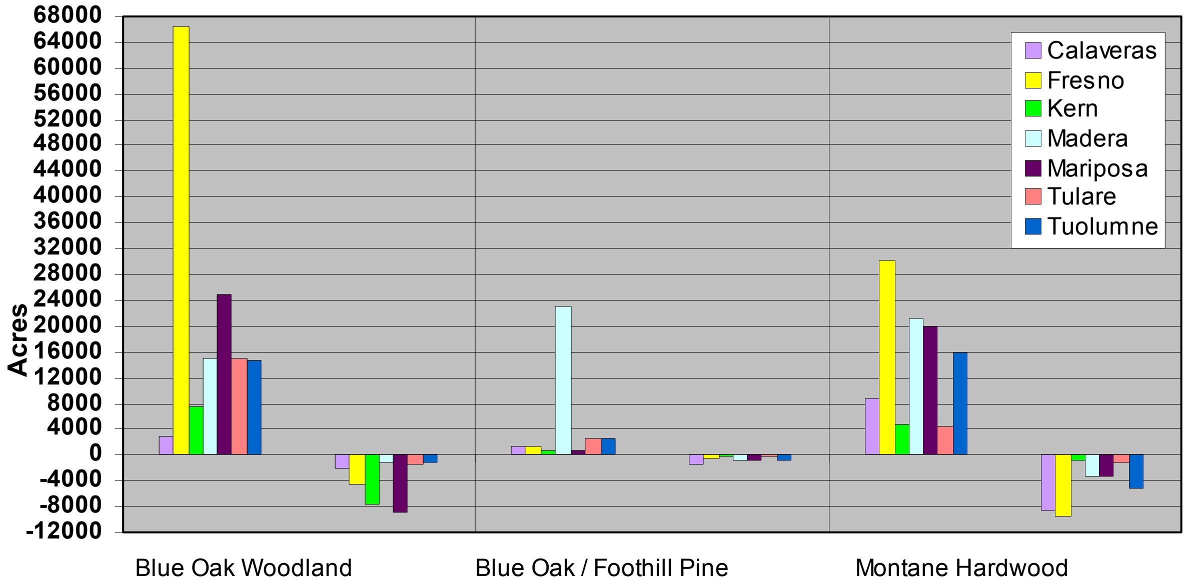
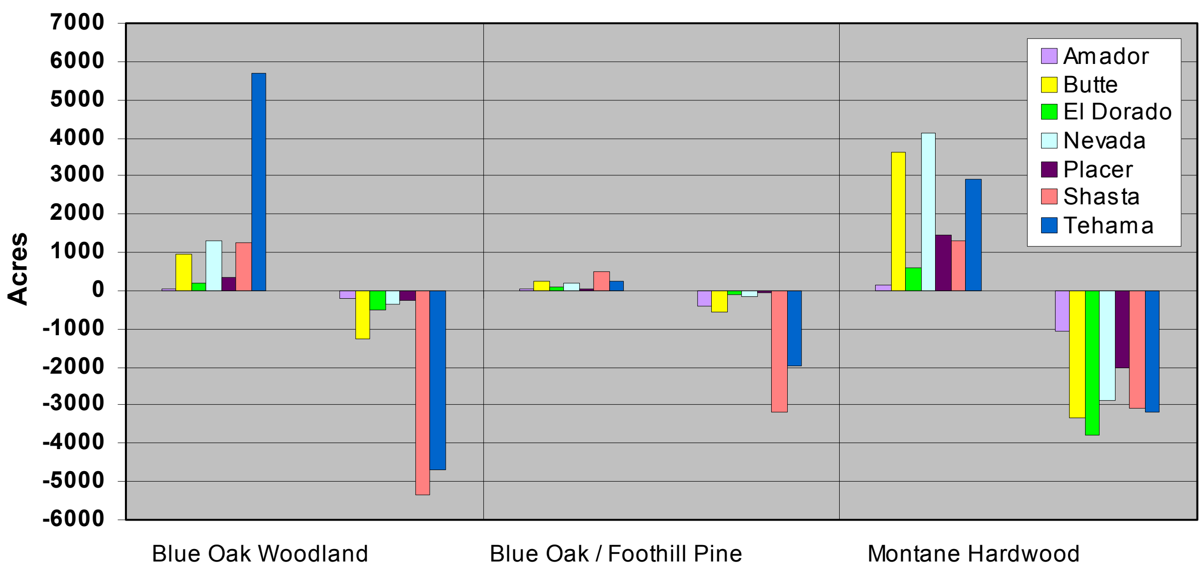


Figure 5. Acres of classified change by hardwood type and county



The causes of hardwood change by county are displayed in Table 4. Verified acres represent the total area that has identified cause of change. The acres verified represent change areas that are attributed to some cause. The percentages represent a portion of the total verified acres. The largest cause of change is attributed to wildfire. Harvesting is the largest source of change in Kern, Amador, Butte and Shasta counties. Development or regeneration are major contributors of change in Mariposa, Placer, and Tuolumne counties.

Table 4. Percentage of Verified Hardwood Change by County

County	Verified Acres	Wildfire	Rx Fire	Harvest	Development	Regeneration	Thinning	Seasonal
Calaveras	11,962	49%	5%	9%	4%	24%	8%	1%
Fresno	5,254	68%	4%	1%	9%	8%	10%	0%
Kern	988	20%	27%	41%	0%	0%	0%	12%
Madera	3,806	2%	10%	45%	10%	3%	10%	19%
Mariposa	12,117	10%	16%	15%	5%	49%	3%	2%
Tulare	723	62%	0%	12%	14%	0%	12%	0%
Tuolumne	6,095	67%	0%	0%	4%	26%	2%	0%
Amador	1,362	7%	19%	35%	17%	0%	1%	12%
Butte	4,475	12%	6%	26%	13%	14%	3%	25%
El Dorado	1,693	37%	0%	7%	23%	6%	1%	13%
Nevada	5,422	68%	0%	10%	3%	7%	0%	12%
Placer	1,036	2%	0%	24%	11%	25%	0%	38%
Shasta	8,722	29%	2%	31%	6%	5%	16%	12%
Tehama	10,550	87%	0%	2%	4%	0%	1%	7%

All images were co-registered using a third-order affine transformation model. Overall root mean square errors of 0.5 pixel to 0.25 pixel were obtained for all image pairs using this model. Table 5A-C displays the error matrix for the project area. The overall accuracy of the change map is 89.3 percent. This means that of the 300 sample sites, 268 were correctly classified (the reference and classified classes are the same). Errors of commission (reference class included in the wrong classified class) and omission (reference class excluded from the correct classified class) are also evident. For example, in Table 5A one site is classified as LDVC when the reference class shows it was actually MDVC. Therefore, one area was omitted from the correct MDVC class and committed to the incorrect LDVC class. The producer's accuracy of each change class ranged from 67 percent to 100 percent and the user's accuracy ranged from 60 percent to 100 percent (Table 5B, 5C). Producer's accuracy represents how well the reference data of each change class is classified. User's accuracy indicates the probability that a given change class actually represents that same change on the ground.

Table 5A. Change Map Accuracy Assessment for the Project Area

Classified As		Reference Class								
		LDVC[1]	MDVC	SDVC	NCH	SIVC	MIVC	LIVC	NVG	TOTAL
	LDVC	8	1							9
	MDVC	1	12	7						20
	SDVC	1	2	30						33
	NCH			8	150	5			3	166
	SIVC					38	1	1		40
	MIVC					2	14			16
	LIVC							9		9
	NVG								7	7
	TOTAL	10	15	45	150	45	15	10	10	300

Table 5B				*Table 5C*		
Producer's Accuracy				User's Accuracy		
LDVC	8/10	80%		LDVC	8/9	89%
MDVC	12/15	80%		MDVC	12/20	60%
SDVC	30/45	67%		SDVC	30/33	91%
NCH	150/150	100%		NCH	150/166	90%
SIVC	38/45	84%		SIVC	38/40	95%
MIVC	14/15	93%		MIVC	14/16	88%
LIVC	9/10	90%		LIVC	9/9	100%
NVG	7/10	70%		NVG	7/7	100%

The accuracy assessment also shows how well the methods classify decreases and increases. Areas classified as a decrease were always a decrease, although the correct class was not always assigned. The same is true for the areas classified as an increase. The small decrease and increase classes have sites classified into the little to no change class (eight and five out of 45, respectively). This error is expected, however, as this type of change can be very subtle and the methods will have difficulty detecting it.

Discussion

The LCMMP produces change data portraying vegetation canopy cover increases and decreases over five-year time periods. The change classes span a continuum from large decreases to large increases in vegetation cover. These classes are qualitative and represent the diversity found in natural landscapes. Each change class has overlap within and between classes, providing a valuable qualitative assessment of change. A quantitative or categorical assessment offers a more comprehensive representation of change, but requires validation from many ground measurements.

The high accuracies of these data enable the monitoring of hardwood rangelands across large areas. These data easily detect large changes in vegetation cover, such as those resulting from development, harvest and wildfire. They also detect more subtle changes including thinning. Caution must be made because vegetation increases are not always representative of increases in hardwood canopy. In some cases they are related to seasonal variation and successional characteristics, such as growth of grass or

[1] LDVC - large decrease in vegetation cover; MDVC - moderate decrease in vegetation cover; SDVC - small decrease in vegetation cover; NCH - little to no change in vegetation cover; SIVC - small increase in vegetation cover; MIVC - moderate increase in vegetation cover; LIVC - large increase in vegetation cover; NVG - non-vegetation change; CLD/SHA - cloud or shadow

shrub following a disturbance. Hardwood types with low canopy cover are particularly sensitive to this phenomenon due to the presence of understory grasses and shrubs.

Identifying the cause of change provides additional information for observing trends over the landscape. Causal information is most easily obtained using available statewide databases, such as fire history and forest practice. Private landowners provide information on activities altering the landscape through IHRMP coordinated workshops. Resource managers can integrate this knowledge into existing policies, maps and plans for a greater understanding of what is occurring on the landscape. This information also may aid in predicting future conditions or determining appropriate management methods.

The IHRMP is one mechanism to promote effective education in assessing voluntary compliance with hardwood resource protection standards, hardwood resource management results and trends in hardwood resource use. Recognizing the value of monitoring data over large areas and its ability to provide various degrees of change, counties have begun to explore the utility of these data. In Fresno County, the change data were presented to private landowners and the Fresno Resource Conservation District as an educational tool for assessing local voluntary guidelines for hardwood rangeland conservation. Napa County, in collaboration with the IHRMP, is assessing the utility of the change data for local planning issues, including identifying changes in riparian and wetland cover, mapping patterns of urban development, locating conversion of agricultural land and open space to urban uses, and monitoring habitat fragmentation. Future efforts focus on analyzing policy issues and trends in land cover over time using these data.

Conclusion

The LCMMP directly addresses CDF's need for a long-term monitoring strategy to inform discussion of issues centered on California's hardwood rangelands. CDF now has the ability to identify trends in hardwood rangeland structure, health, resource use and other factors that affect long-term viability across large regions. The LCMMP provides critical information on the impacts management decisions and natural forces have on the environment. This information includes the actual location and extent of change with respect to the ground, three levels of vegetation cover increase and decrease and the cause of change. Knowing the location and extent of vegetation change provides a picture of the distribution and concentration of change areas. The levels of change give an indication of the severity of vegetation removal or vigor. Understanding what is causing these changes creates an awareness of the impacts change agents have on the landscape.

The LCMMP produces other benefits by providing monitoring data to other agencies, private interest groups and stakeholders. These data can answer the different question these entities may have at different spatial scales. At regional scales, ecosystem characteristics or function can be investigated by examining the cause of change over time, the balance of vegetation increase and decrease, and whether changes are temporary or permanent (e.g., fire versus development). Examining changes in vegetation at a more sub-regional or local scale can help resource managers evaluate the impacts of disturbances on natural resources of local interest. This information is useful to assess the effectiveness of existing policies, programs, management activities and regulations, and to develop alternatives as needed (e.g., county voluntary guidelines for oak woodland management). Finally, these data provide a valuable tool for the IHRMP to work with landowners and state and local governments in resolving hardwood issues.

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